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SNS-FES MEBT

MECHANICAL SUBSYSTEMS

MEBT SUPPORT FRAME (25B1996) DESIGN CALCULATIONS

This engineering note documents the safety parameters and design calculations for the Spallation Neutron Source - Front End Systems Medium Energy Beam Transport (SNS-FES MEBT) Support Frame, LBNL Drawing number 25B1996, and it's associated parts. This note covers the following areas of the Support Frame's design.

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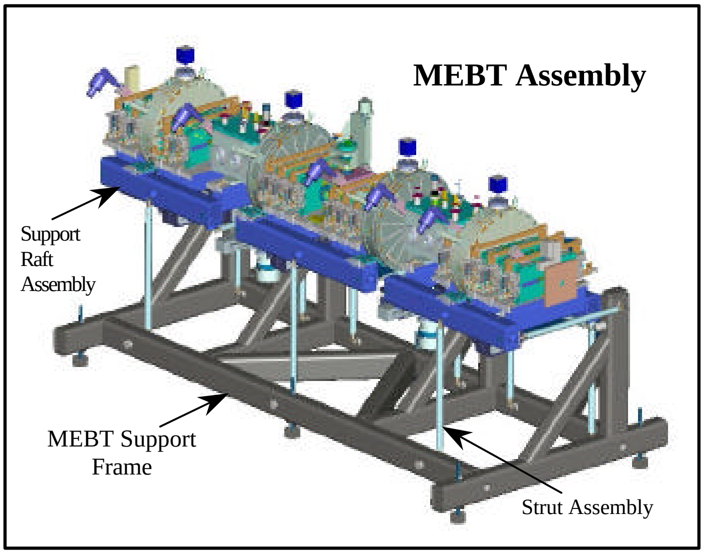
1.0 Overview of the Design and Requirements

This note describes the design details and calculations for the Support Frame for the Spallation Neutron Source - Front End Systems Medium Energy Beam Transport (SNS-FES MEBT) Support Assembly. The MEBT Assembly is an ion beam transport/diagnostic system which is being built and tested at LBNL. The MEBT Assembly will ultimately be shipped to Oakridge National Laboratory for installation in the front-end system of the Spallation Neutron Source machine.



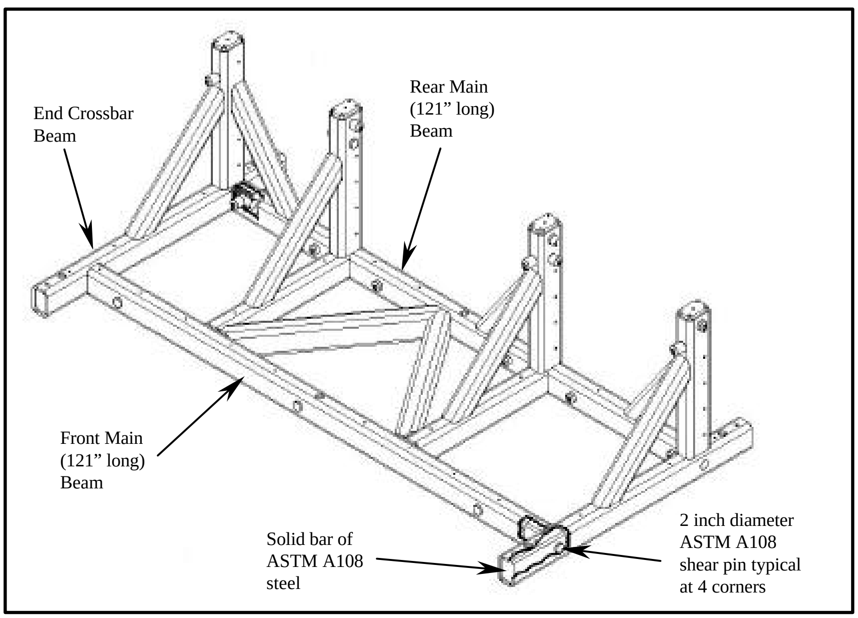
There are two primary design constraints for the Support Frame. The first is to provide a solid platform for precise alignment of the MEBT Support Raft Assemblies during operation. We would also like to be able to move and handle the MEBT Assembly with a minimal amount of disassembly and re-assembly in order to save cost and schedule delays. The lifting and handling of the assembly is necessary to prepare the MEBT Assembly for shipping (the details of packaging/handling and shipping will be analyzed and addressed in a separate note). Considering the above shipping requirements, the second primary design constraint is to provide a rigid structure that can be used as a lifting, handling and shipping device. A heavy design has been chosen for the Support Frame because it must be able to carry all loads during lifting, handling and shipping operations without allowing excessive deflection or stresses to the three MEBT Raft Assemblies or the interconnecting bellows.

The complete assembly is approximately 11 feet long, 5 1/2 feet wide and 6 feet high. It weighs about 8,780 pounds. The handling of the MEBT Assembly qualifies as a high-consequence/high-value lift because of the cost and lead time for construction, and must meet all of the requirements of Pub. 3000 (5.4.7.3 and 5.4.9). Any damage to the MEBT Assembly would significantly delay the progress of the SNS program.

2.0 Designing This Structure as a Lifting Fixture as described in LBNL Pub. 3000, Chapter 5.4.9

The Support Frame is regarded as a lifting fixture because the entire MEBT Assembly will be lifted on this structure. The lifting points are tapped holes passing through the beam wall and into solid steel blocks inserted into each end of the end crossbar beams. These tapped holes will provide at least 2 diameters of thread engagement for safety hoist rings.

The Support Frame is designed so that no welds are under any shear or tensile loads during lifting and that all lifting forces are directed through solid structural members. In this case, the solid structural members are 2-inch diameter, ASTM A108, shear pins pressed into holes drilled in solid blocks of ASTM A108 steel. The ASTM A108 steel blocks are welded into the ends of the rectangular tubing before the tubing is welded together. After the Support Frame is completely welded together, 2" diameter holes are drilled through the end cross beam/steel block and into the end of the main beam steel block. A 2" diameter pin is then pressed into the hole and welded into place. See the illustration below.



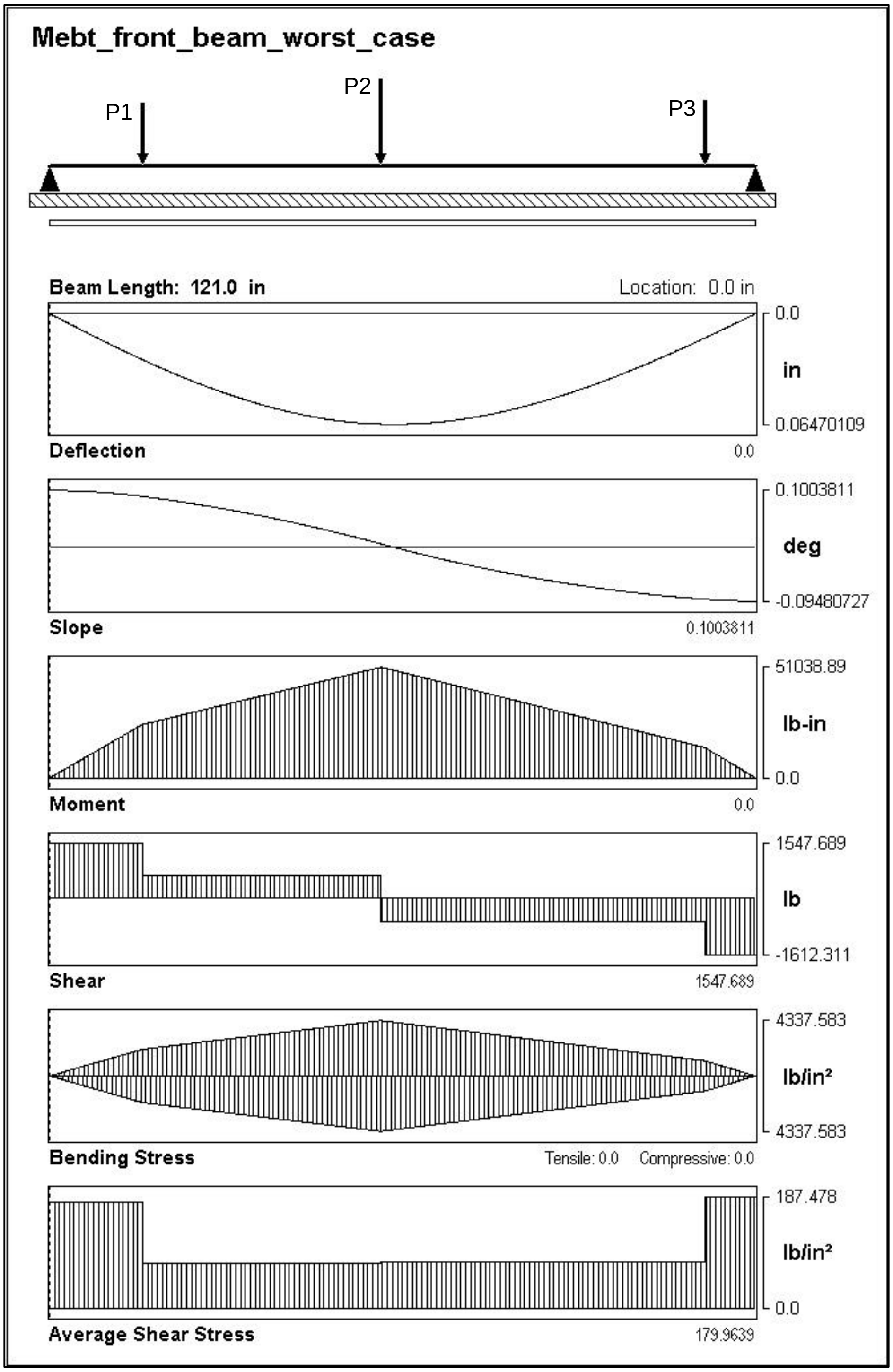
Per Pub.3000 the stresses in the structural members must be designed to a minimum safety factor of 5 with respect to the ultimate strength of the material. The material used for the front, back and crossbar beams is ASTM A500 Grade B structural tubing, with an ultimate strength of 58,000 psi. The strut bosses are ASTM A108 bar, with an ultimate strength of 85,000 psi. The design weight of the entire MEBT Assembly is approximately 8780 pounds (this is slightly more than expected and allows for variations in the weights of the attached equipment).

2.1 Loads in Support Frame Beams

The calculations will consider worst case loading scenarios for the two main (121” long) beams and end crossbar beams. The weight of the raft assemblies will be considered to be point loads on the strut mounting locations. The loads from the raft through the struts to the frame were assumed to be symmetrical about the z axis (along the length of the structure). The values for P1, P2, P3 etc. were therefore taken to be one half the total load on the side of the raft with only one strut and a quarter of the load (biased relative to the raft CG) on each of the struts on the two strut side of the raft

2.1.1 Loads on Main Beams

The results of the worst case analysis of the main front beam and the main rear beam are shown in the plots below. The calculated portion of the total weight of each raft is shown as a concentrated force at the appropriate strut mounting locations. The beams are modeled as a two point simply supported beams.



** Mebt_front_beam_worst_case **

BEAM LENGTH = 121.0 in

MATERIAL PROPERTIES
Carbon Steel:
Modulus of elasticity = 30000000.0 lb/in²
Stress limit = 58000.0 lb/in²

CROSS-SECTION PROPERTIES
6x4Steel Beam:
Moment of inertia = 35.3 in^4
Top height = 3.0 in
Bottom height = 3.0 in
Area = 8.6 in²

EXTERNAL CONCENTRATED FORCES
P1: 902.0 lb at 15.91 in
P2: 1314.0 lb at 56.82 in
P3: 944.0 lb at 112.37 in

SUPPORT REACTIONS ***
R1: Simple at 0.0 in
Reaction Force =-1547.689 lb

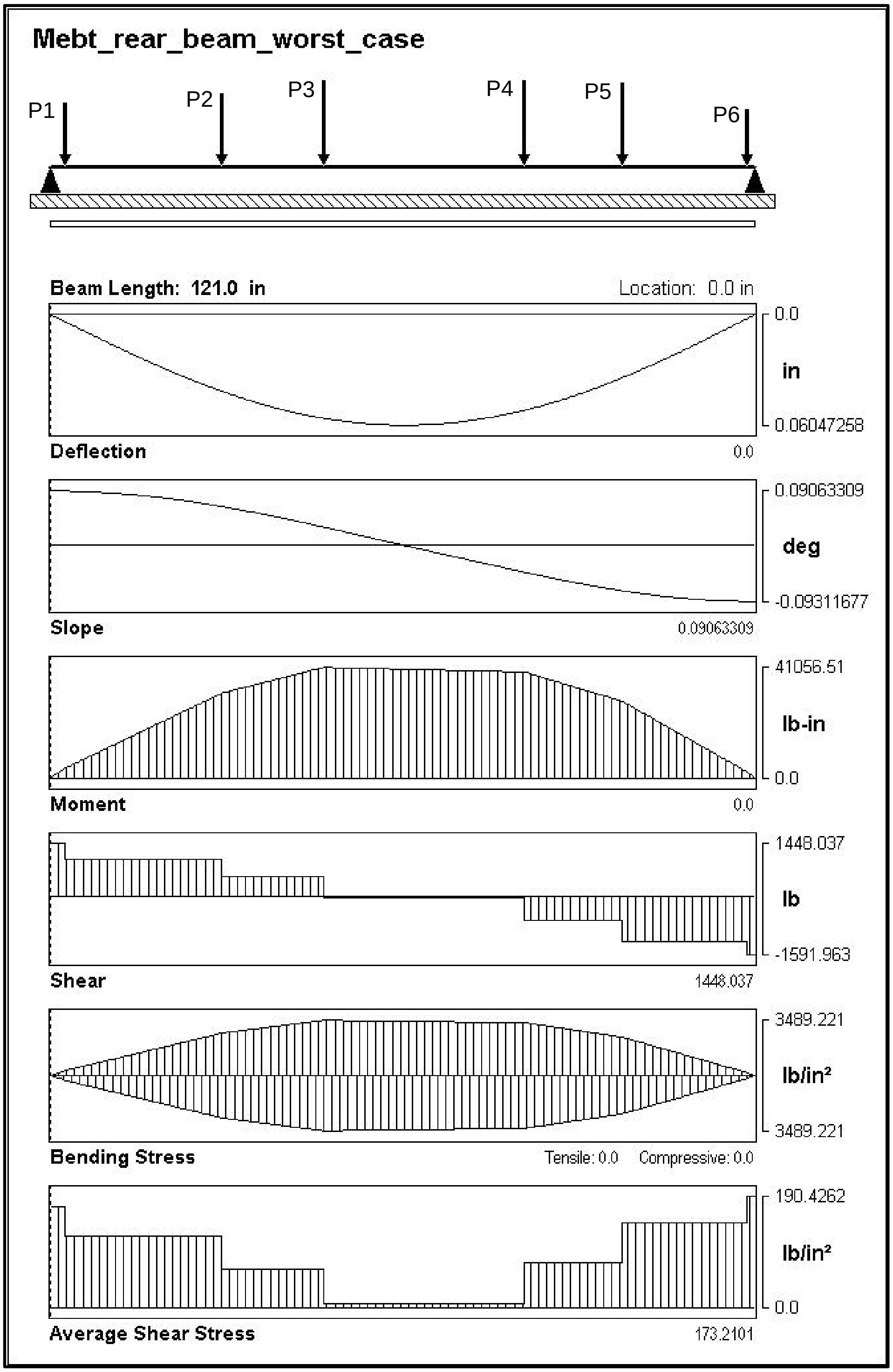
R2: Simple at 121.0 in
Reaction Force =-1612.311 lb

MAXIMUM DEFLECTION ***
0.06470109 in at 59.04257 in
No Limit specified

MAXIMUM BENDING MOMENT ***
51038.89 lb-in at 56.82 in

MAXIMUM SHEAR FORCE ***
-1612.311 lb from 112.37 in to 121.0 in

MAXIMUM STRESS ***
Tensile = 4337.583 lb/in²
Compressive = 4337.583 lb/in²
Shear (Avg) = 187.478 lb/in²



** Mebt_rear_beam_worst_case **

BEAM LENGTH = 121.0 in

MATERIAL PROPERTIES
Carbon Steel:
Modulus of elasticity = 30000000.0 lb/in²
Stress limit = 58000.0 lb/in²

CROSS-SECTION PROPERTIES
6x4 Steel Beam:
Moment of inertia = 35.3 in^4
Top height = 3.0 in
Bottom height = 3.0 in
Area = 8.36 in²

EXTERNAL CONCENTRATED FORCES
P1: 414.0 lb at 2.5 in
P2: 488.0 lb at 29.5 in
P3: 597.0 lb at 46.93 in
P4: 597.0 lb at 81.43 in
P5: 577.0 lb at 98.27 in
P6: 367.0 lb at 119.52 in

SUPPORT REACTIONS ***
R1: Simple at 0.0 in
Reaction Force =-1448.037 lb

R2: Simple at 121.0 in
Reaction Force =-1591.963 lb

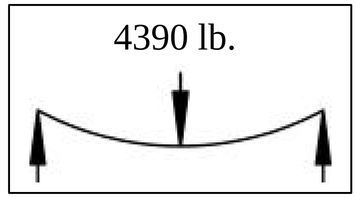
MAXIMUM DEFLECTION ***
0.06047258 in at 60.76973 in
No Limit specified

MAXIMUM BENDING MOMENT ***
41056.51 lb-in at 46.93 in

MAXIMUM SHEAR FORCE ***
-1591.963 lb from 119.52 in to 121.0 in

MAXIMUM STRESS ***
Tensile = 3489.221 lb/in²
Compressive = 3489.221 lb/in²
Shear (Avg) = 190.4262 lb/in²

2.1.2 Loads on End Crossbar Beam



4 x 6 x 1/2 wall box tube, $I = 35.3 \quad s = 11.8$

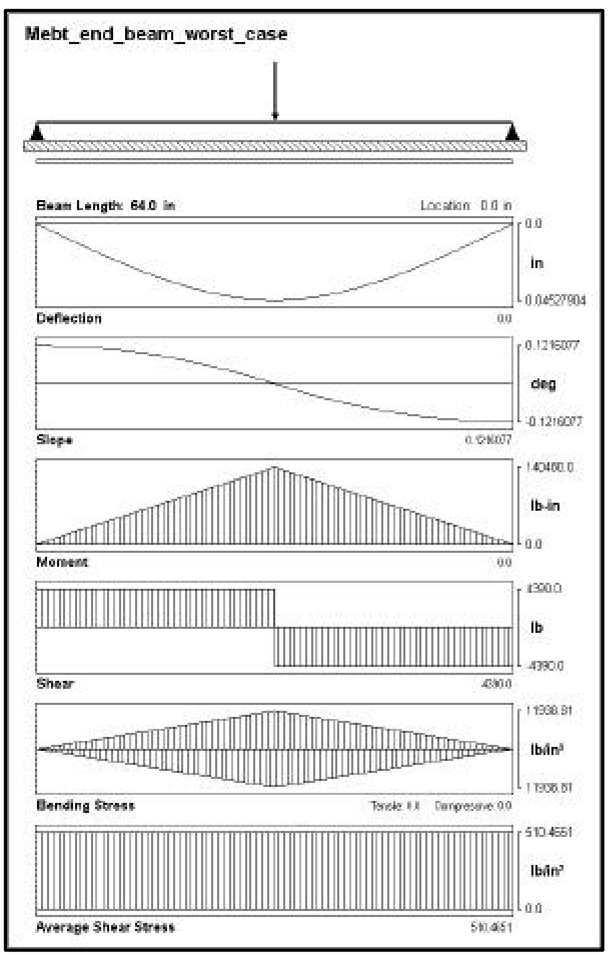
$$\sigma = \frac{Wl}{4s} = \frac{4390\,(64)}{4(11.8)} = 5952 \ psi \Rightarrow 9.7SF$$

In case one it is assumed that one cross bar carries half the total load (the total predicted weight of the rafts and Support Frame is 8780 pounds):

In case two, a worst case scenario, it is assumed that the cross bar carries the full load:

The results of the worst case scenario, where the total weight of the structure is placed at the center of one beam, are displayed graphically in the following plots.

$\sigma = 11490 \ psi \Rightarrow 5.0SF$



** Mebt_end_beam_worst_case **

BEAM LENGTH = 64.0 in

MATERIAL PROPERTIES
Carbon Steel:
Modulus of elasticity = 30000000.0 lb/in²
Stress limit = 58000.0 lb/in²

CROSS-SECTION PROPERTIES
6x4Steel Beam:
Moment of inertia = 35.3 in^4
Top height = 3.0 in
Bottom height = 3.0 in
Area = 8.6 in²

EXTERNAL CONCENTRATED FORCES
P1: 8780.0 lb at 32.0 in

SUPPORT REACTIONS ***
R1: Simple at 0.0 in
Reaction Force =-4390.0 lb

R2: Simple at 64.0 in
Reaction Force =-4390.0 lb

MAXIMUM DEFLECTION ***
0.04527904 in at 32.0 in
No Limit specified

MAXIMUM BENDING MOMENT ***
140480.0 lb-in at 32.0 in

MAXIMUM SHEAR FORCE ***
4390.0 lb from 0.0 in to 32.0 in
-4390.0 lb from 32.0 in to 64.0 in

MAXIMUM STRESS ***
Tensile = 11938.81 lb/in²
Compressive = 11938.81 lb/in²
Shear (Avg) = 510.4651 lb/in²

2.1.3 Discussion

This particular computer analysis does not include the cross bracing incorporated into the actual design of the MEBT Support Frame. The cross bracing will increase the stiffness and reduce the stress and deflection (see section 5.4). This worst case scenario for the two main beams also does not take into account a center supporting foot. Looking at the front main beam and using the simply supported beam model as a near worst case scenario the maximum tensile/compressive stress is 4337.583 lb/in². The front main beam has a 1¼” hole drilled through it, in the direction of the maximum stress, at approximately the center of the span. A stress concentration factor has to be allowed for and the appropriate stress concentration factor is approximately 2.2.

Therefore 4337.58psi multiplied by 2.2 = 9542.68psi.
The safety factor for this beam would be:

$$SF = \frac{UTS}{\sigma} = \frac{58000\ psi}{9542\ psi} = 6.1$$

The rear main beam has a maximum tensile/compressive stress 3489.221 lb/in² that yields a safety factor of 16.6. As with the front main beam, the rear main beam has a 1¼” hole drilled through it in the direction of the maximum stress so the stress concentration factor has to be calculated in. This yields a maximum stress value of 7676.24 that equates to a safety factor of 7.6.

The end crossbar beam, in the worst case scenario yields a safety factor of 5.

These results satisfy the Pub. 3000 requirement that the stresses in the structural members must be designed to a minimum safety factor of 5 with respect to the ultimate strength of the material.

2.2 Loads in Shear Pins

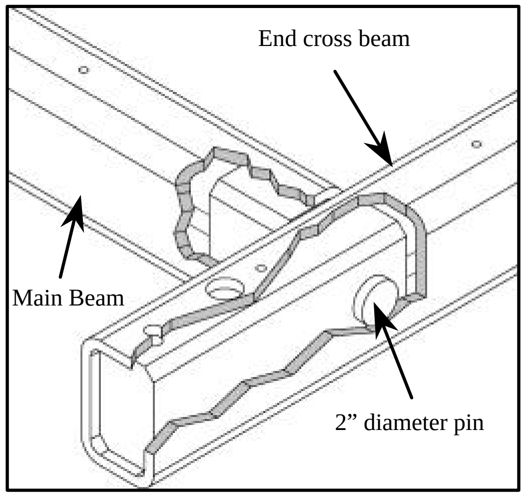
The shear in the 2" diameter pins driven through the hole in the end cross beams and into the ends of the two main (121" long) beams, assuming the entire weight of the structure (8780 lbs.) is applied, is:

$$A = \frac{\pi(2)^2}{4} = 3.14\,in^2$$

$$\sigma = \frac{8780}{3.14} = 2796\ psi$$

$$For\ ASTM\ 108\ UTS = 85000\ psi$$

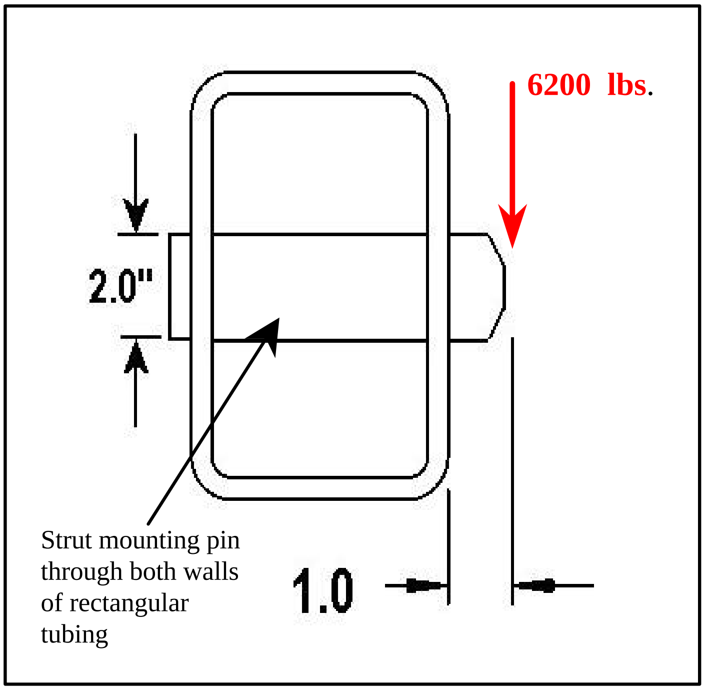
$$\therefore SF = 30.4$$



2.3 Loads on Strut Mounting Bosses

The MEBT Support Frame and the Support Raft strut mounting bosses have been designed so that none of the welds are in direct shear. The 2" diameter mounting pins pass through at least one wall (1/2" wall thickness) and in most cases through both walls of the 6" by 4" rectangular tubing. This means that the mounting pins can be considered to be carrying the total load and that the welds carry approximately zero load.

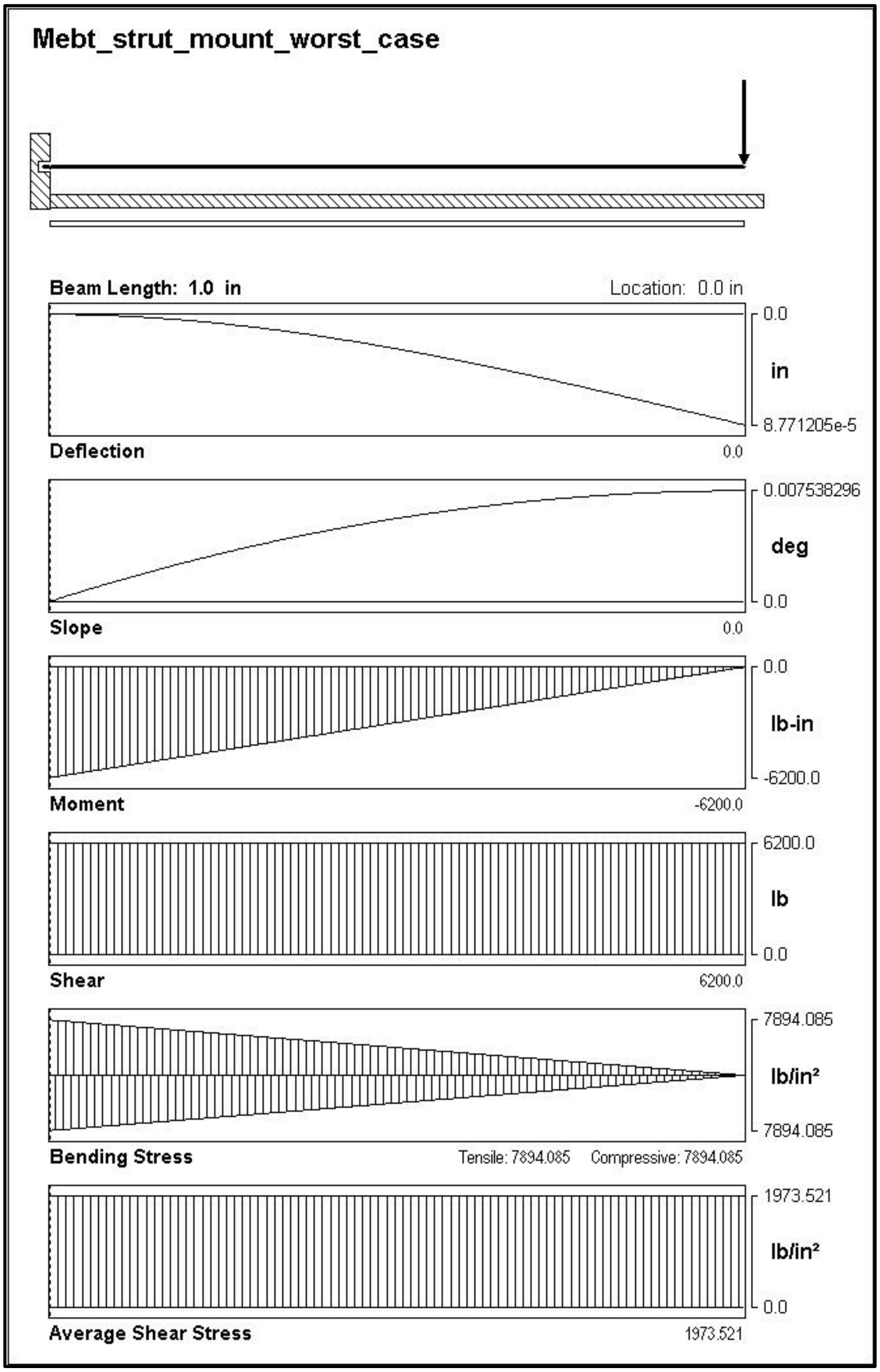
In a worst case scenario, a single 2" diameter mounting pin will carry the total MEBT Support Raft load (all 3 rafts). The combined weight of all three rafts is approximately 6200 pounds (see illustration below).



The strut 2” diameter mounting pins have cross-sectional properties of:
Area = 3.141593 in²
Moment of inertia = 0.7853982 in^4

The external concentrated force is assumed to be:
3 Rafts = 6200.0 lb (at 1.0 in)

The illustration below shows the results of calculations for a worst case scenario of the strut to MEBT Support Frame and the strut to Support Raft mounting points. The results show that the mount pins have a safety factor in shear of 43 and a safety factor in tension/compression of 10.8.



BEAM LENGTH = 1.0 in

MATERIAL PROPERTIES
Strut Mount:
Modulus of elasticity = 30000000 lb/in²
Stress limit = 85000.0 lb/in²

CROSS-SECTION PROPERTIES
Moment of inertia = 0.7853982 in^4
Top height = 1.0 in
Bottom height = 1.0 in
Area = 3.141593 in²

EXTERNAL CONCENTRATED FORCES
3 Rafts: 6200.0 lb at 1.0 in

SUPPORT REACTIONS ***
Strut Mount: Fixed at 0.0 in
Reaction Force =-6200.0 lb
Reaction Moment =-6200.0 lb-in

MAXIMUM DEFLECTION ***
0.00008771205 in at 1.0 in
No Limit specified

MAXIMUM BENDING MOMENT ***
-6200.0 lb-in at 0.0 in

MAXIMUM SHEAR FORCE ***
6200.0 lb from 0.0 in to 1.0 in

MAXIMUM STRESS ***
Tensile = 7894.085 lb/in²
Compressive = 7894.085 lb/in²
Shear (Avg) = 1973.521 lb/in²

2.4 Strength of Struts

The strength of the struts, which connect the MEBT Raft Assemblies to the Support Frame will now be considered. The struts work in a kinematic 6-strut system where 3 struts provide vertical support, 2 struts horizontal support in one direction and the sixth strut horizontal support 90° to the other horizontal struts. The highest load a strut will encounter is the single horizontal (z-direction) strut in a 1g seismic or shipping event. Under normal circumstances the single horizontal Z struts would encounter virtually no load. The maximum 1g load on a z-strut would be conservatively 3000 pounds.

For the strut in tension it is the weld area that is the limiting factor. The weld area, for a 1.75” diameter tube with a .15” x 45° weld prep turned on its ends, is approximately .548 in^2. With a weld strength of 72,000 psi the strut welds are capable of withstanding a tensile load of 39,456 pounds. In compression the limiting factor is buckling from inelastic stability.

For buckling the critical load is :

$$Load_{critical} = P_{critical} = \frac{c\pi^2 EI}{\lambda^2} = \frac{(1)\pi^2(30\times10^6).34}{24^2} = 174{,}774 \text{ lb.}$$

where :

End condition constant $= c = 1$ (both ends pinned)

Length $= \lambda = 24$ in

Modulus for steel $= E = 30 \text{ x } 10^6$ psi

Moment of Inertia $= I = .34 \text{ in}^4$

Weight of any one raft = 3000 pounds

$$\therefore \text{SF} = \frac{176{,}576}{3000} = 58.8$$

For buckling the critical stress is :

$$\sigma_{critical} = \frac{P_{critical}}{A} = \frac{\pi^2 E}{\left(\frac{\lambda}{r}\right)^2} = \frac{\pi^2(30\times10^6)}{\left(\frac{24}{.54}\right)^2} = 149{,}895$$

where :

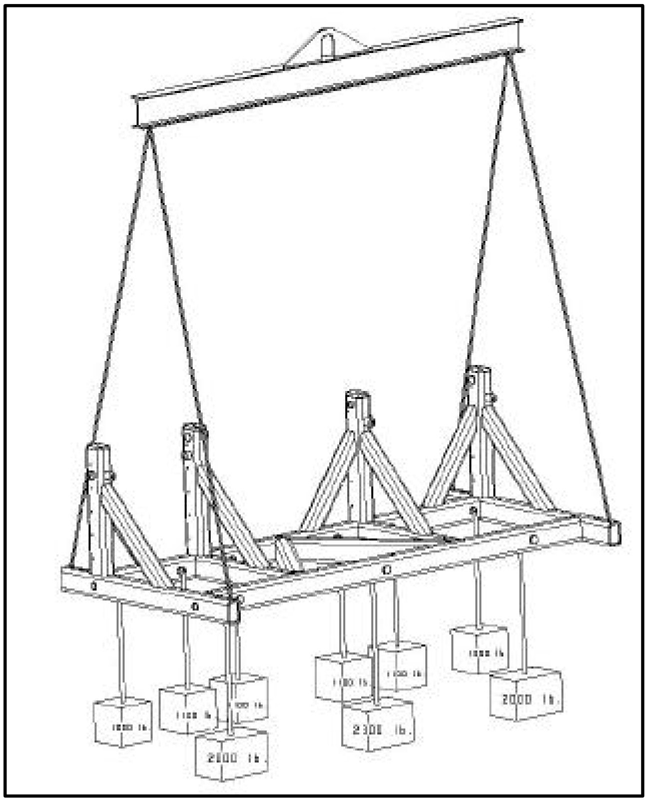
Area $= A = 1.178 \text{ in}^2$

Radius of gyration $= r = \sqrt{\frac{I}{A}} = .54$ in

The above results indicate that the strut itself is stiff enough to withstand the load placed on it from any raft. The rod ends are capable of withstanding a load of 11,518 pounds in tension or compression. This is the limiting item and if the conservative estimate of 3000 pounds is assumed for any one raft it yields a safety factor of 3.84. This is only an issue in the event of an earthquake and only on the Z struts. Under normal operations and during lifting and handling the highest strut loads are on the three vertical struts. These loads are conservatively 2000 pounds per strut, which yields a safety factor of 5.76. For further information please refer to Engineering Note M7272, "Strength and Compliance of Beamline Struts"

3.0 Proof Testing

Proof testing of the Support Frame may be accomplished by crane lifting, as described in the illustration and photo below, with dummy loads at each of the nine vertical strut attachment points. The MEBT Assembly is estimated to have a weight of 8780 pounds. The MEBT Raft Assemblies have an estimated combined weight of 6200 pounds. This will be distributed to the Support Frame at each of the strut mounting points. In accordance with the Pub 3000 requirements, each of these loads is approximately doubled for the proof testing. The approximate (double) loads are illustrated in the diagram below. The photo shows the actual lift test in progress. After proof testing and before painting all welds were visually inspected and die-penetrant tested for defects.

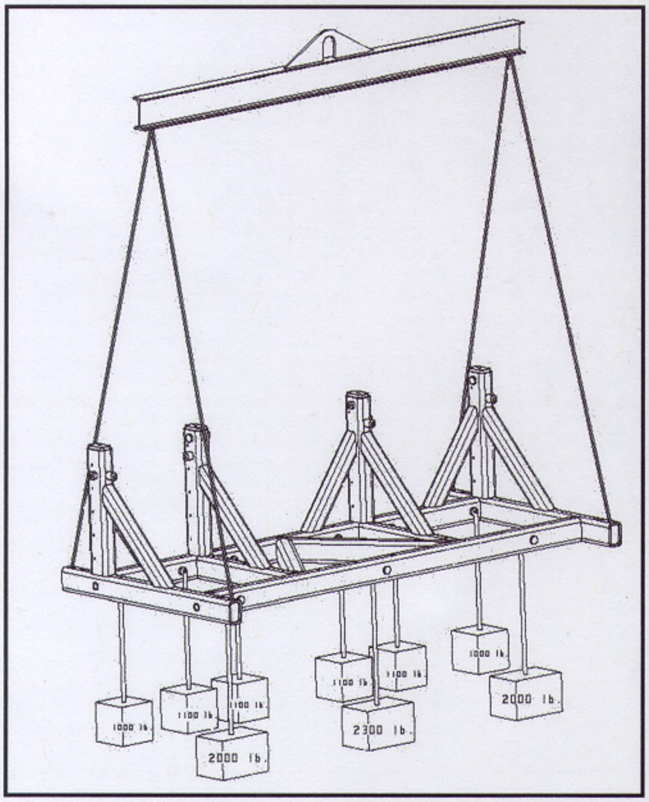


Proof testing performed by Kevin Tregalas ______________________________Date__________________

Witnessed by Allan DeMello _________________________________Date__________________

Witnessed by Derek Shuman _________________________________Date__________________

Witnessed by Daryl Oshatz _________________________________Date__________________



Proof testing performed by Kevin Tregalas Kevin Tregalas Date 6-10-02

Witnessed by Allan DeMello Allan DeMello Date 6/7/2002

Witnessed by Derek Shuman Derek Shuman Date 6/7/02

Witnessed by Daryl Oshatz Daryl Oshatz Date 6/10/02

4.0 Mechanical Design Analysis

The mechanical design analysis investigates six specific areas critical to the design of the Support Frame. Finite element analysis (FEA) is used extensively in the mechanical design analysis that follows. ANSYS 5.6 was used as the FEA modeling software.

The first area of the design analyzed is the static deflection and stress of the MEBT Assembly with 1g of acceleration applied in the y-direction. This analysis will simulate the effects of gravity on the Support Frame in its stationary operational configuration.

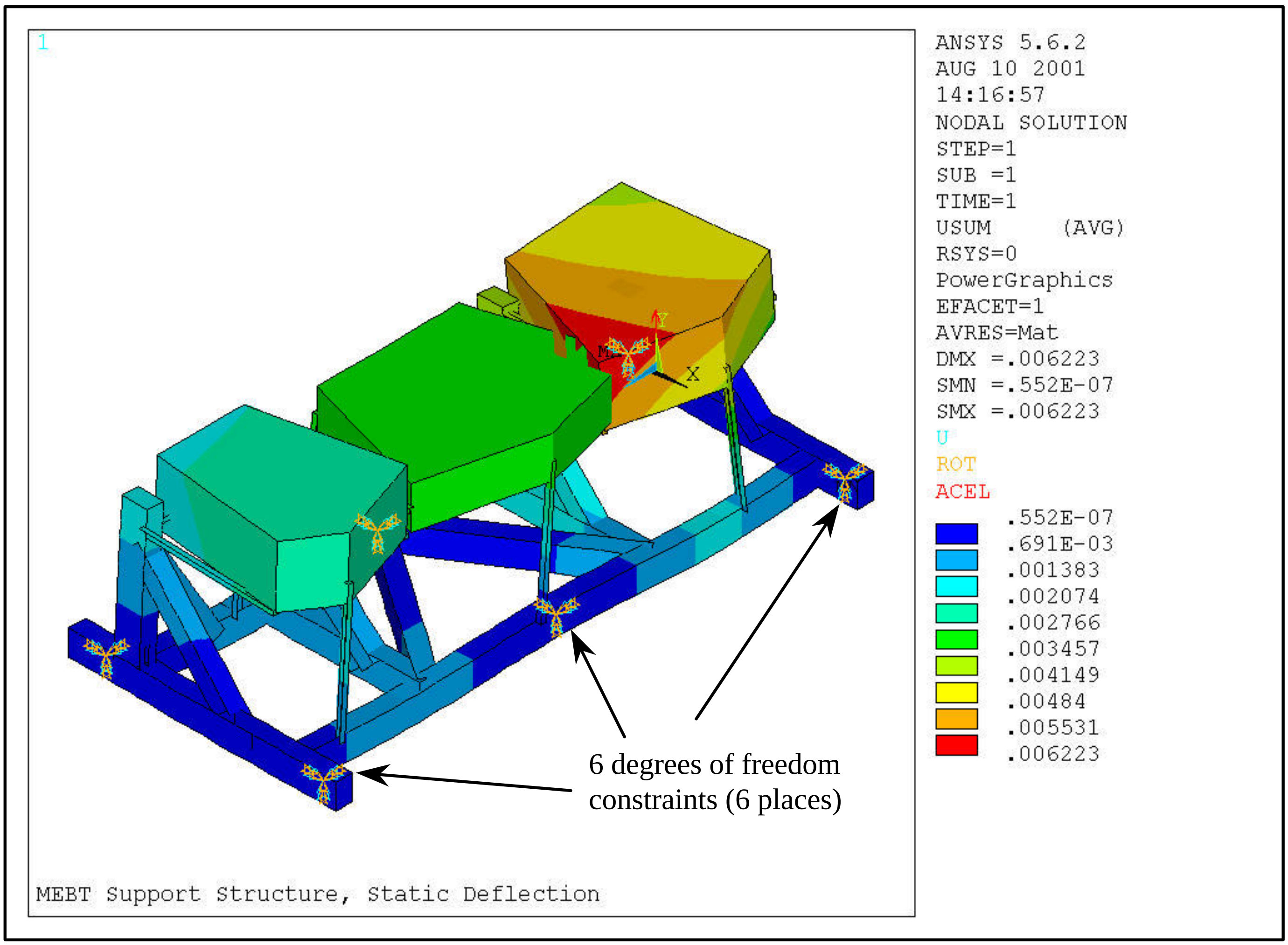
The Support Frame will not only serve as the base for the support and alignment of the MEBT Raft Assemblies, but it will also act as the lifting and shipping structure. The second area studied in the design analysis pertains to the deflection and stress encountered by the Support Frame during a lifting/handling situation. The large beam members of the structure are used to insure that the bellows, joining the MEBT Raft Assemblies together, are not over stressed from excess deflection during lifting/handling and shipping of the MEBT Assembly. The third section presents the analysis for torsion in the Support Frame should the MEBT Assembly be set down on two opposing corners of the Support Frame. The Support Frame must keep the MEBT Raft Assemblies and therefore the inter-connecting bellows from over twisting. Fourth, the consequences of an unlikely overturn accident of the MEBT Assembly are analyzed in terms of the deflection and stress on the Support Frame. Deflection and stress from an applied seismic load (i.e. Earthquake) in both the x and the z directions is developed in the fifth section. Finally the natural frequencies are analyzed to determine if the Support Frame will withstand harmonic vibrations. It is desirable to keep the natural frequency above 10Hz to avoid vibration amplification factors and transmission of those vibrations into the MEBT Raft Assemblies.

4.1 FEA Model Description

The ANSYS 5.6 finite element model is constructed using three main element types. The Support Frame portion of the model is constructed using key points and lines. The lines are then meshed as beams (BEAM4) with cross sectional properties of 6” x 4” x ½” wall or 4” x 4” x ½” wall where appropriate. The material properties used in the Support Frame are for steel. The Support Rafts are virtually massless volumes with a point mass (MASS21) at their approximate center of gravity. The struts are modeled as nodes and lines and meshed with the LINK8 element. The material properties used in the struts are for steel. A spring constant was determined for the different lengths of the physical struts and their mounting bosses. These spring constants were then used to calculate the LINK8 cross sectional area keeping the modulus at E= 30E6 psi. The Support Rafts are attached to the struts and through the struts to the frame.

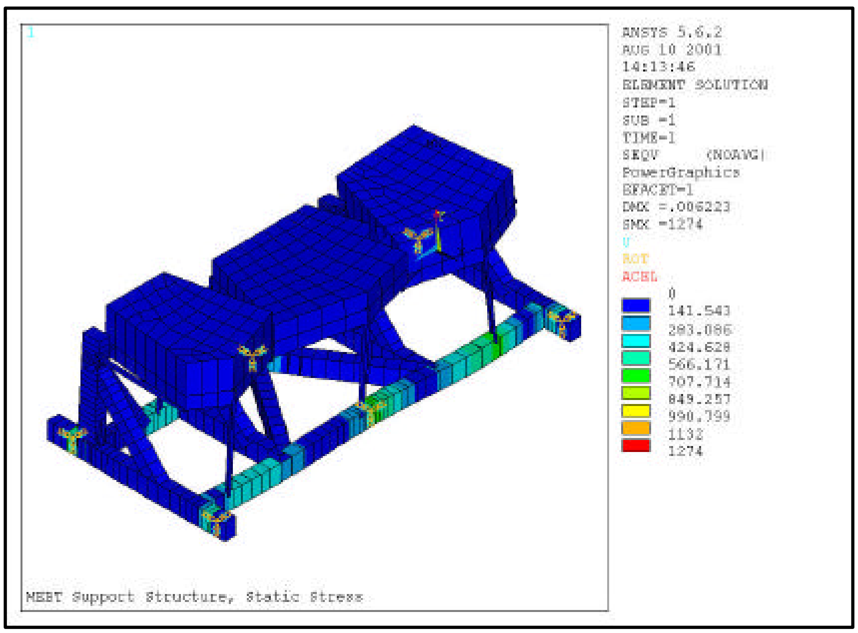
4.2 Static Deflection

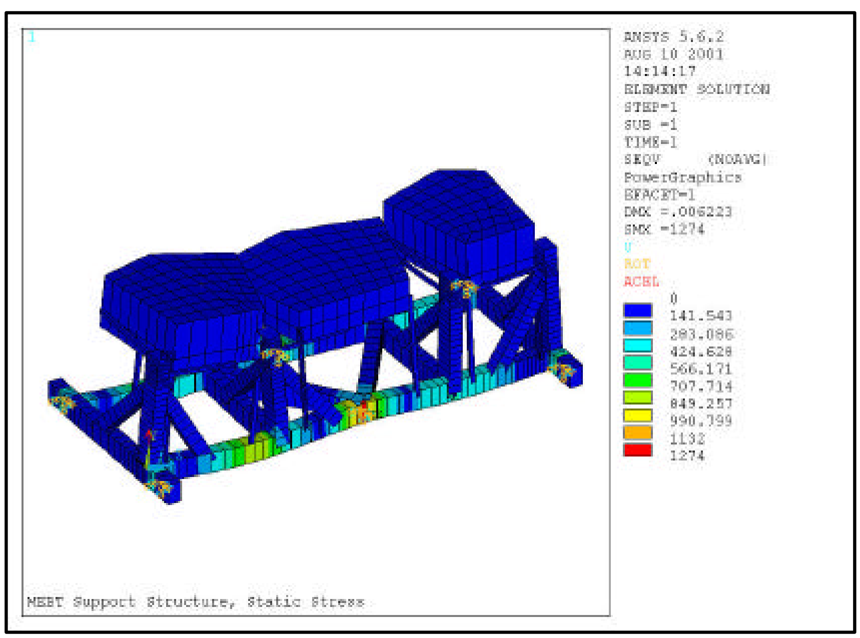
The illustration below is a static deflection plot of the ANSYS 5.6 Finite Element model of the MEBT Assembly. The frame is constrained in all six degrees of freedom at the six locations where it will be bolted to the floor. The maximum deflection in the solution is 0.0062 inches. The strut system is designed to completely compensate for all of the deflection in the MEBT Assembly in the static condition.



4.3 Static Stress

The illustrations below are of the front and back view of the static stress solution in ANSYS. The frame is constrained in all six degrees of freedom at the six locations where it will be bolted to the floor. The maximum stress calculated in the solution is 1274 psi.

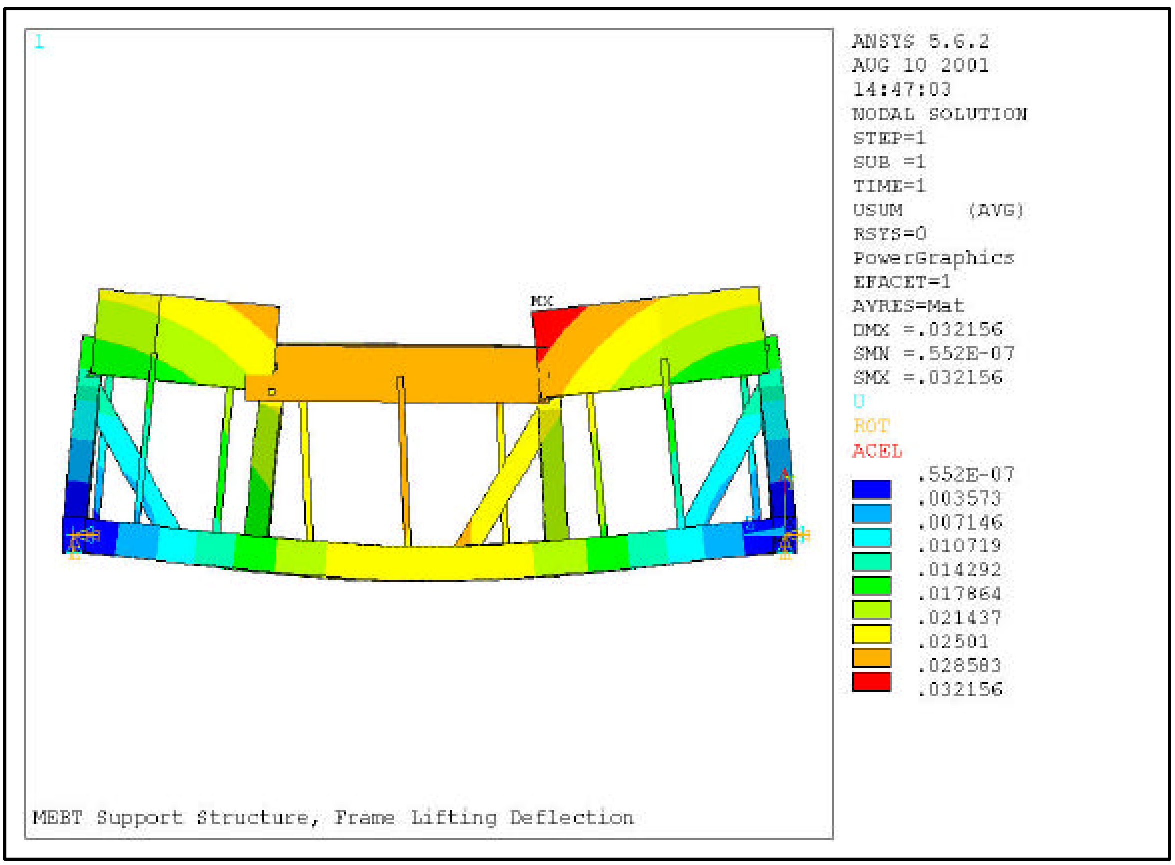




4.4 Lifting/Handling Deflection

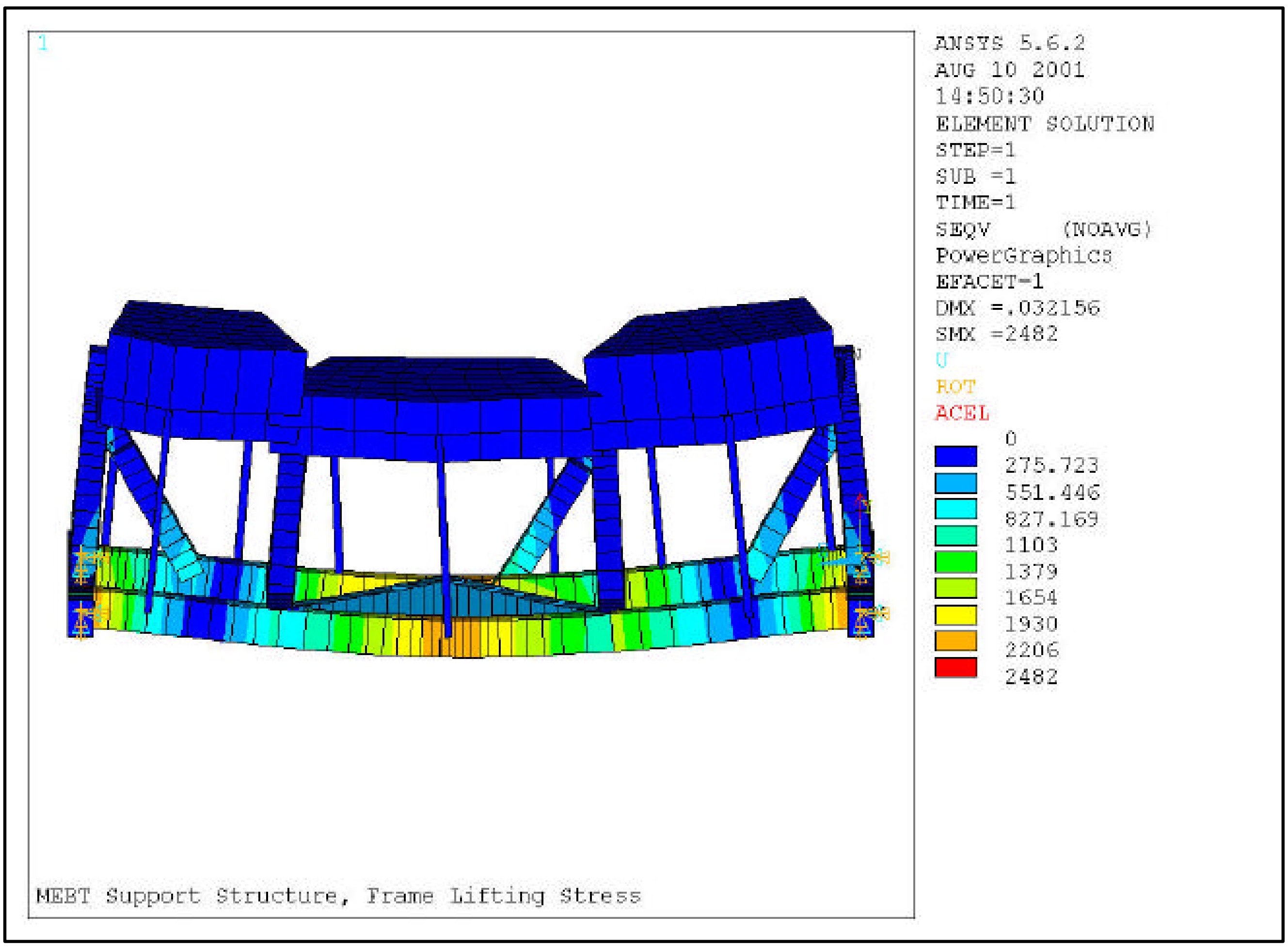
ANSYS predicts a considerable reduction of the deflection in the Support Frame, in a simulated lifting arrangement, as compared to the worst case analysis developed in section 3.1.1. The maximum deflection is predicted to be 0.032" in the area of the rafts, as compared to 0.0647" for the simply supported beam (at the beam) .

When the deflection is broken down into its constituent parts it shows that there is virtually no movement in the x direction (0.001"), a slight movement in the y direction (0.009") and a 0.023" movement in the z direction. More accurate deflection quantities can be obtained from the model by focusing on the elements that are approximately in the location of the bellows interconnecting the rafts. Between rafts 1 and 2 the maximum deflection is in the z direction and the quantity is approximately 0.016". Between rafts 2 and 3 the maximum deflection is also in the z direction and the quantity is approximately 0.029". This amount of movement, especially since the majority of it is in the z-direction, is well within the capabilities of the bellows inter-connecting the rafts (Refer to Engineering Note M7857 by James T. Goulding and Engineering Note M7972 by Andrew Zachoszcz).



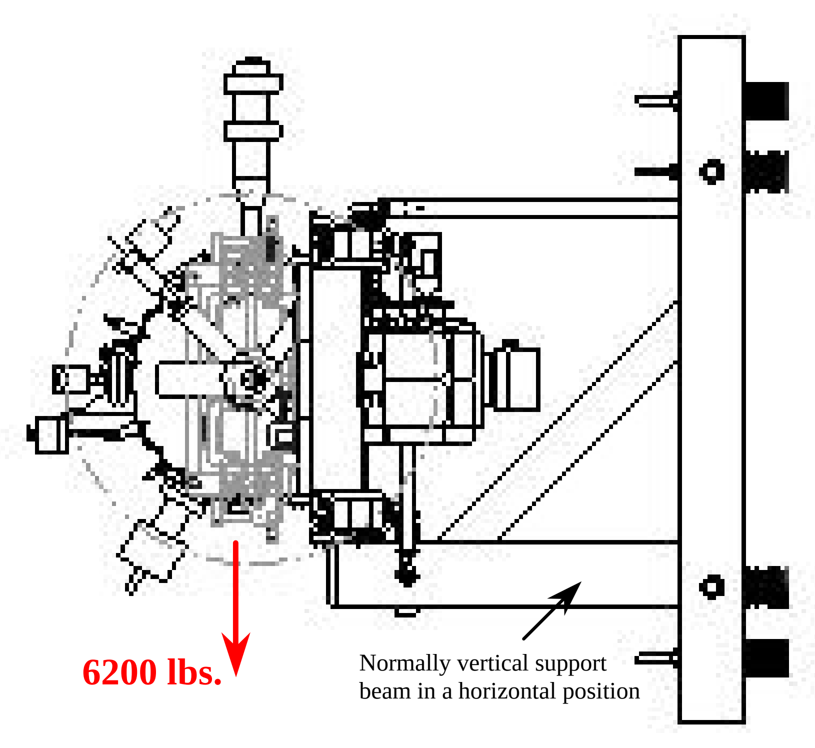
4.5 Lifting/Handling Stress

ANSYS also predicts a considerable reduction of the stresses in the Support Frame in a simulated lifting arrangement. The maximum stress is 2482 psi (compared to 4337.583 lb/in² for the simply supported beam). The maximum stress is also concentrated in the region where the two horizontal diagonal crossbeams meet the rear main beam. The hole through the frame (in approximately the center of the span) for the mounting bolt creates a stress riser and as in section 3.1.3. A stress concentration factor of 2.2 is assumed which yields a maximum stress in the Support Frame of 5,460 psi that yields a safety factor of 10.6.



4.6 Overturning Analysis

With proper rigging an over turn accident that would alternately load the Support Frame is not possible. However we must evaluate the loads (in the worst case condition) on the Support Frame should this happen. In this case two lifting points would carry the entire weight of the assembly. In addition the weight of the MEBT Raft Assemblies and attached equipment (approximately 6200 pounds) would be carried by the four horizontal support beams through six vertical struts. In this case the loads would still not directly act on the welds since the strut mount pins pass through the wall of the 6” x 4” beam in both the Support Frame and the Support Rafts. This case is only looked at to show adequate strength in an accident scenario.



Overturned MEBT Assembly

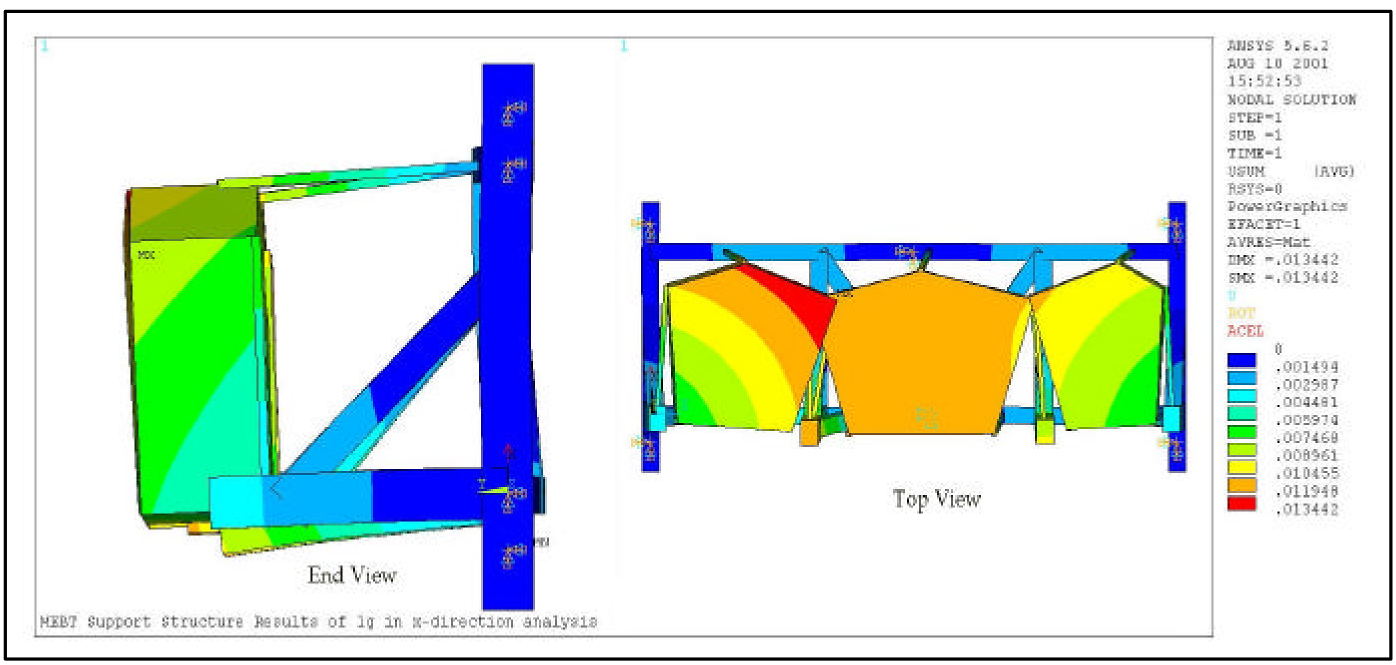
To analyze an overturn event a 1g force is applied to the ANSYS model in order to simulate the deflection and stress on the Support Frame if it were to overturn.

The ANSYS model predicts a maximum deflection in the MEBT Assembly, of 0.0134". The predicted maximum deflection on the bellows can be approximated by analyzing the model in the area between the rafts. Breaking out the data relative to the MEBT coordinate system (x, y and z directions) the predicted maximum deflections are:

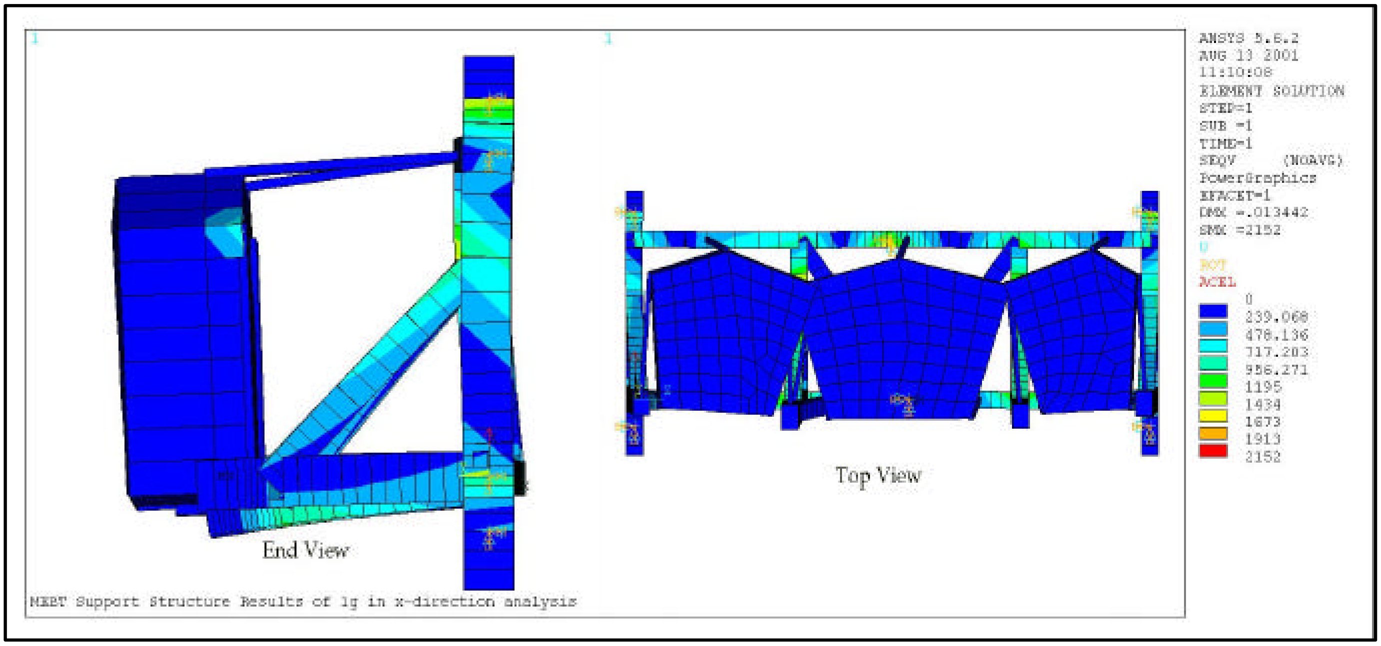
Between rafts 1 and 2	Between rafts 2 and 3
X= ~0.003	X= ~0.0035
Y= ~0.001	Y= ~0.001
Z= ~0.011	Z= ~0.002

The bellows will take up these deflections without any excessive stress (Refer to Engineering Note M7857 by James T. Goulding and Engineering Note M7972 by Andrew Zachoszcz).

The illustration below is a (composite) deflection plot of the ANSYS model with the 1g acceleration applied in the x direction to simulate an overturn event. The image is plotted in the rotated (overturned) position.



The illustration below is a (composite) stress plot of the ANSYS model with the 1g acceleration applied in the x direction to simulate an overturn event. The image is plotted in the rotated (overturned) position.

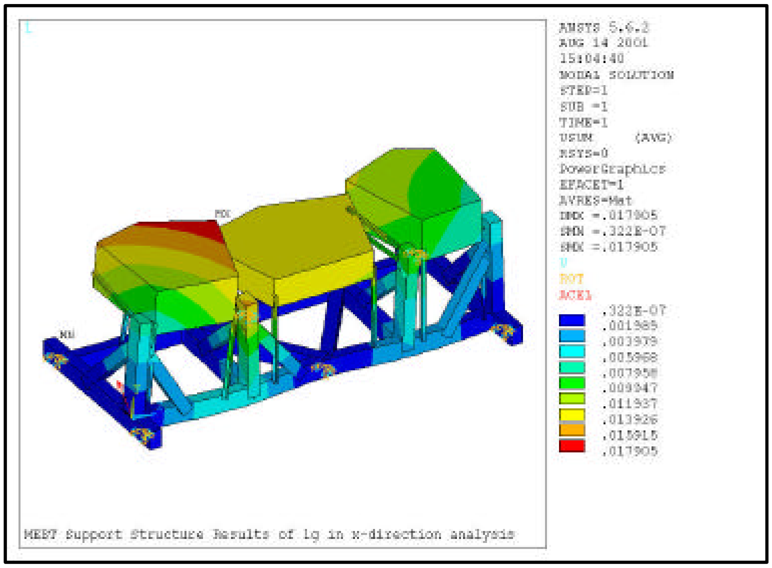


The maximum stress in the assembly is predicted to be 2152 psi. This stress is concentrated in the portion of the frame where the two diagonal horizontal crossbeams meet the rear main beam. A stress concentration factor of 2.2 is assumed which yields a maximum stress in the Support Frame of 5,460 psi which yields a safety factor of 27.

4.7 Lateral Acceleration Analysis

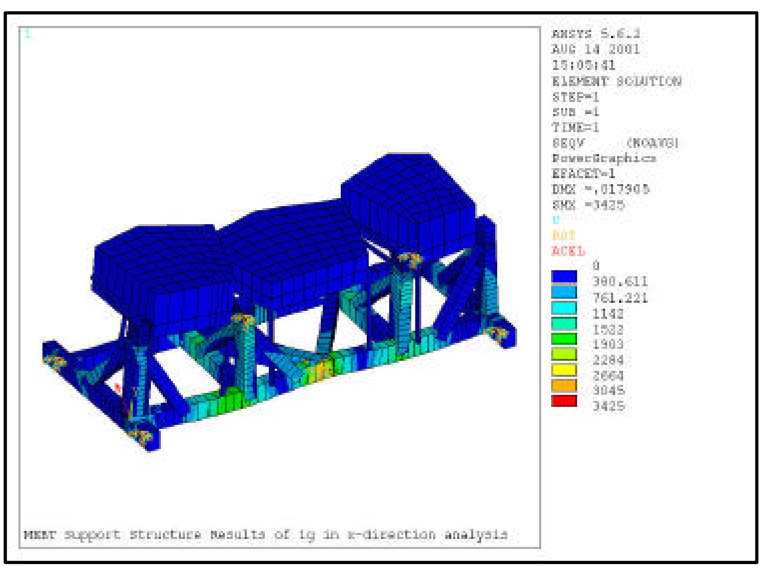
Lateral accelerations were analyzed to simulate an acceleration/deceleration event in the shipping and handling of the MEBT Assembly. Lateral acceleration analysis of the MEBT Assembly was done with a 1g acceleration applied in two different ways. Case one has a 1g acceleration applied in the x and y directions and the second case has a 1g acceleration applied in the y and z directions.

ANSYS predicts a minimum amount of the deflection in the MEBT Assembly in a 1g lateral acceleration scenario. With a 1g acceleration applied in both the x and y directions the maximum deflection between rafts 1 and 2 (in the area of the bellows) is in the z direction and the quantity is approximately 0.018”. Between rafts 2 and 3 the maximum deflection is in the x direction and the quantity is approximately 0.003 (see illustration below). This amount of movement, especially since the majority of it is in the z-direction, is well within the capabilities of the bellows inter-connecting the rafts (Refer to Engineering Note M7857 by James T. Goulding and Engineering Note M7972 by Andrew Zachoszcz).



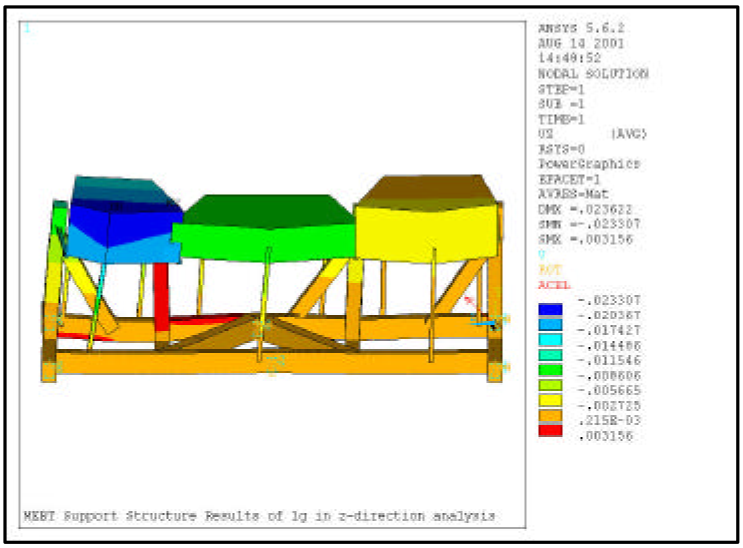
MEBT Support Structure Results of 1g in x-direction analysis

The stress is low (3425psi) relative to the ultimate strength of the material and is concentrated in the area where the diagonal cross beams meet the rear main beam (see illustration below).

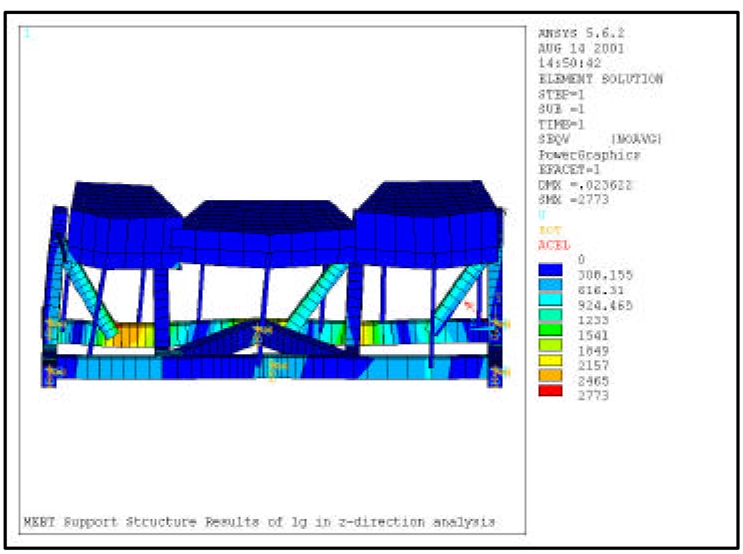


MEBT Support Structure Results of 1g in x-direction analysis

In the second case of the lateral acceleration study a 1g acceleration is applied in both the y and z directions. The maximum deflection between rafts 1 and 2 (in the area of the bellows) is in the z direction and the quantity is approximately 0.007”. Between rafts 2 and 3 the maximum deflection is again in the z direction and the quantity is approximately 0.010” (see illustration below).

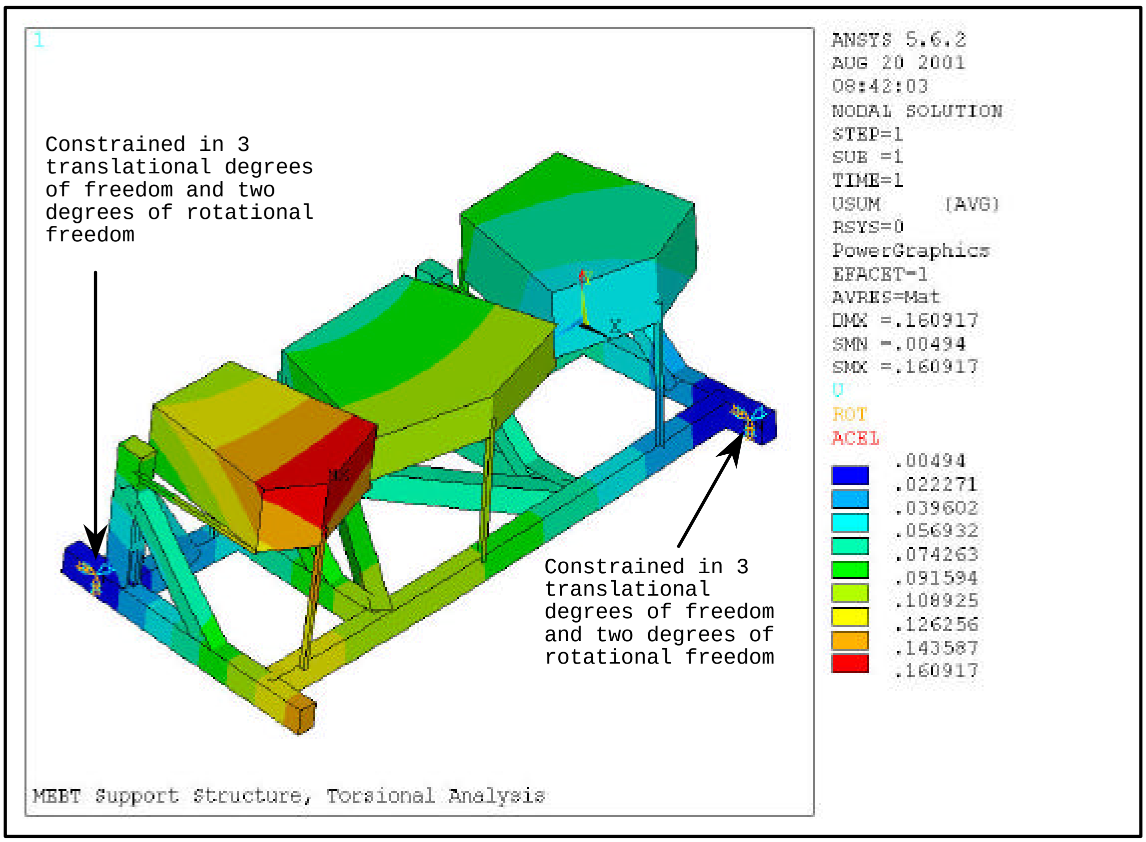


Again the stress is low (2773psi) relative to the ultimate strength of the material (see illustration below).



4.8 Torsional Deflection During Lifting and Handling

The torsional rigidity of the Support Frame was analyzed using ANSYS 5.6. The illustration below is a solution plot of the deflection in the Support Frame in torsion. The Support Frame is constrained in three degrees of translational freedom and two degrees of rotational freedom (i.e. z is allowed to rotate) at two diagonally opposed corners (where it will be bolted to the floor). This arrangement simulates a situation where the MEBT Assembly is set on the ground with support at two corners only.



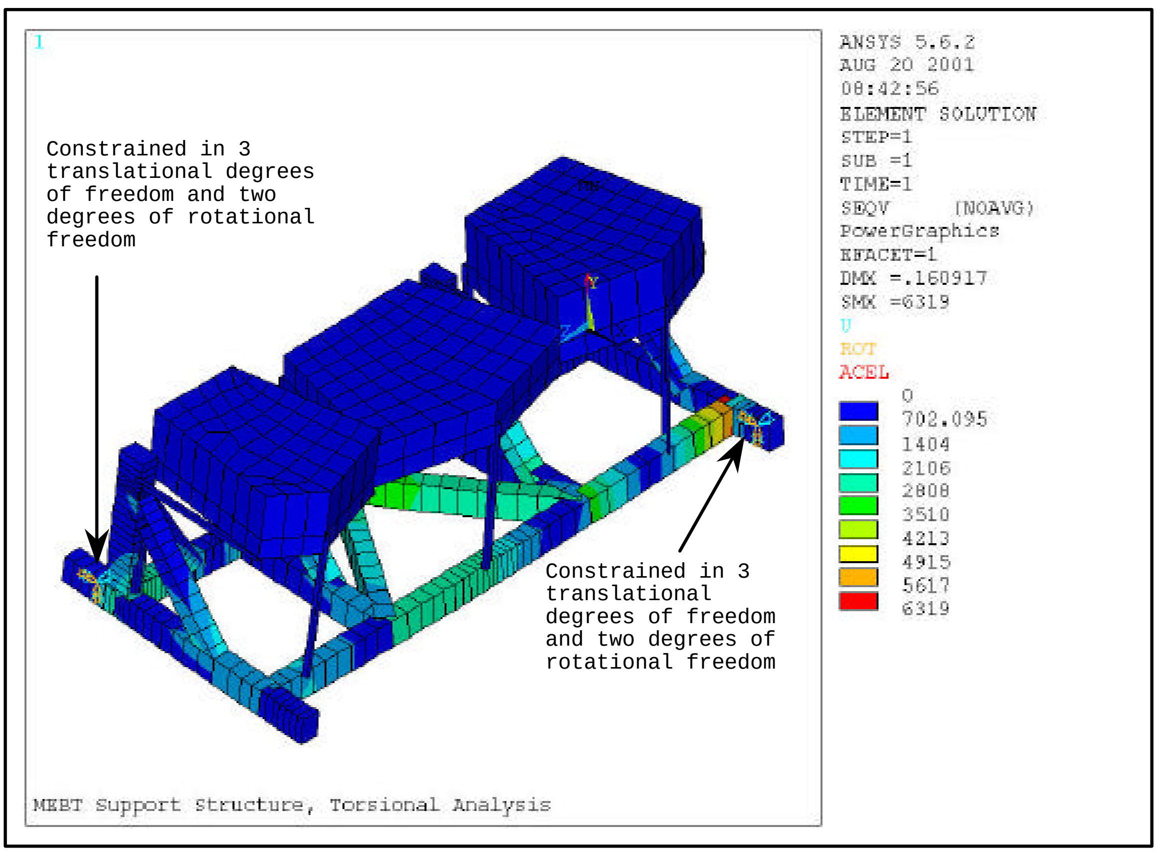
Using the same technique as in the lifting simulation (i.e. analyzing elements in the regions of the inter-connecting bellows) the deflections are predicted to be:

Between rafts 1 and 2	Between rafts 2 and 3
X= ~0.035	X= ~0.043
Y= ~0.036	Y= ~0.020
Z= ~0.027	Z= ~0.033

Even though this scenario is highly unlikely these values for deflection **are too excessive for the inter-connecting bellows and require that the bellows between the rafts be disconnected during any MEBT Assembly handling event** (Refer to Engineering Note M7857 by James T. Goulding and Engineering Note M7972 by Andrew Zachoszcz).

4.9 Torsional Stress During Lifting and Handling

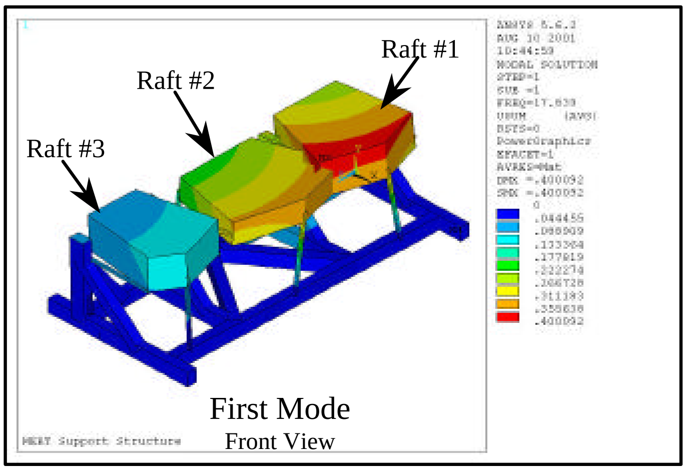
The illustration below is a solution plot of the stress in the Support Frame in torsion. The Support Frame is constrained in three degrees of translational freedom and two degrees of rotational freedom (i.e. z is allowed to rotate) at two diagonally opposed corners (where it will be bolted to the floor). This arrangement simulates a situation where the MEBT Assembly is set on the ground with support at two corners only.



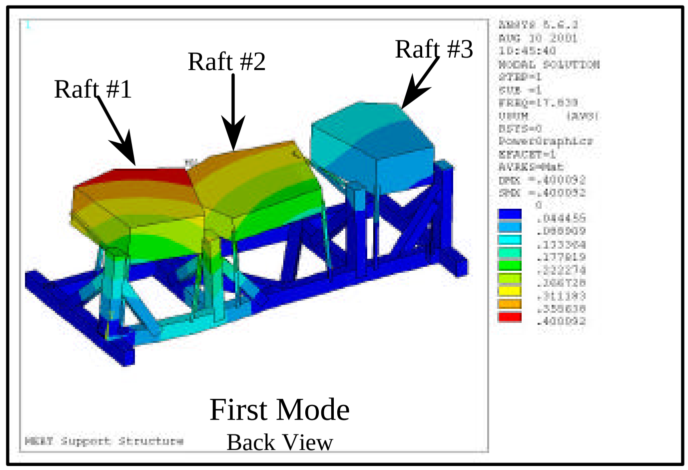
The maximum stress is concentrated in the end cross beam and, even when a stress concentration is factored in, is low relative to the ultimate strength of the material.

4.10 Natural Frequency

The natural frequency analysis was done using ANSYS 5.6 finite element software. The first ten modes were analyzed to determine their natural frequencies. Below is an ANSYS modal plot for the first mode.



First Mode
Front View



First Mode
Back View

Below is a chart of the first four modes, their associated frequencies and some observations from the ANSYS plots.

Mode	Frequency	Observations
1	17.84	The rear main beam bends down in area of raft #1 and the vertical beams supporting raft #1 bend toward each other. As a consequence of the frame movement, rafts 1 and 2 move toward each other. (See ANSYS plots above)
2	20.77	The rear main beam bends up in area of raft #3 and the vertical beams supporting raft #3 bend away from each other. As a consequence of the frame movement, rafts 3 moves away from raft 2.
3	34.81	The front main beam bends up in area of raft #3 and the rear main beam bends down the in area of raft #1. The two vertical beams supporting raft #1 are bent toward raft #2. As a consequence of the frame movement, raft 1 and 2 move toward raft 3.
4	39.76	The front main beam bends down in area of raft #1 and raft #3. The two vertical beams in the center of the Support Frame move toward the front of the structure. The vertical beams on each end bend toward each other. As a consequence of the frame movement, rafts 1 and 3 moves toward raft 2.

The lowest natural frequency of the MEBT Assembly is 17.84 Hz which is above the minimum frequency of 10 Hz.